RADC-TR-65-83

RESEARCH AND DEVELOPMENT ON L-BAND CROSSED-FIELD AMPLIFIER CHAIN

by
H. L. McDowell
A. Wilczek

Report No. 8
Quarterly Progress Report
1 September 1964 to 31 December 1964

Contract Nr. AF 30(602)-2533
ARPA Order No. 136.61

Rome Air Development Center Research and Technology Division
Air Force Systems Command, United States Air Force
Griffiss Air Force Base, New York

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ABSTRACT

During this quarter, life tests were continued on the Group C, SFD-209 Tubes. Tubes L48E and D37F have operated for 4932 hours and 2368 hours respectively. The life test program has now accumulated a total of 11,881 life test hours. Life testing continues.

Construction and RF testing of the group D design tubes was completed. Tube F63F was tested to 1500 watts average power with a 200 microsecond pulse. The performance of tubes F63F and G35F proved that the dependence of performance characteristics on anode-cathode spacing can be predicted. The operating efficiency of tube L7F indicates that, by increasing end hat diameter, the efficiency is raised above 50% at all frequencies in the operating band. Tube J4F indicated that matrix impregnated cathodes, processed in accordance with standard techniques, do not necessarily develop a high secondary emission ratio.

The variations in impedance match from tube to tube can be traced to the design of the susceptive matching tabs and the output and input line assembly technique.

PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact Mr. Schneider, EMATE, Extension 4924.

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1.0 INTRODUCTION

During the quarter covered by this report, high average power tests were conducted on tube F63F. Operation at 1500 watts average power and 200 μsec pulse length were demonstrated simultaneously. These tests were made with the tube operated from a dc power supply with the control electrode turn-off procedure. An energy storage capacitor of 24 microfarads was employed for the 200 μsec pulse length. With this storage capacitor, power output droop during the pulse amounted to between 0.5 db and 1 db, due to the voltage droop obtained with the capacitor.

Life testing was continued during this quarter and, by the end of the quarter, tubes L48E and D37F had operated for 4932 hours and 2368 hours, respectively. Life testing of these tubes is continuing. The life test program has now accumulated a total of 11,881 life test hours.

Construction and RF testing of the Group D design driver tubes was completed. A number of important conclusions have been drawn as a result of experience with this group of tubes. For one thing, we now know that the average power capabilities of the present design are at least one and probably several kilowatts. We have further learned the cause of some of the tube-to-tube performance variations and have found ways to improve the efficiency and reduce the range of currents over which "low current instabilities" occur.

By the end of December, the program of this contract was essentially completed. Phase measurements of some of the tubes is the one task remaining. The phase measurement set up is now being assembled.

2.0 HIGH AVERAGE POWER TESTS

Since we do not have a long pulse L-band driver available, it was necessary to conduct the simultaneous tests of high average power and long pulse capability using a feedback loop technique. Figure 1 shows a block diagram of the system employed. The magnetron driver, which is also used for most of our RF characterization, is employed as a trigger signal in this long pulse test. The pulse length from this magnetron is 3 µsec. During this initial trigger interval, the crossed-field amplifier is driven directly by the magnetron. At the end of this trigger interval, the amplifier continues to be self-excited by the feedback loop. At the end of the desired long pulse, the control electrode pulse is applied to the amplifier to turn it off. Once turn off has occurred, the amplifier waits for the application of the next magnetron trigger pulse without drawing current. In this manner, the output pulse length is controlled by the time delay introduced between the magnetron trigger pulse and the control electrode turn-off pulse. Figure 2 shows waveforms obtained for a 25 µsec pulse length. The initial amplification period of approximately 3 µsec may be clearly discerned. The total attenuation in the feedback loop was comparatively high; i.e., approximately 17 db. Therefore, during the self-excited interval, the amplifier was operated at 17 db gain. This resulted in an effective input power between 1 kilowatt and 2 kilowatts peak (17 db below measured output) - a comparatively low value for this tube. This in turn resulted in a lower output power during the self-excited period as compared with the output when driven by the magnetron during the initial trigger interval. Figure 3 shows the pulse shapes obtained with a 200 µsec pulse length. In this case, the initial 3 µsec trigger interval is barely visible. The pulse droop is between 0.5 db and 1 db during the 200 µsec period. These tests were run with a 24 microfarad energy storage capacitor. The observed droop is approximately what would be predicted from a

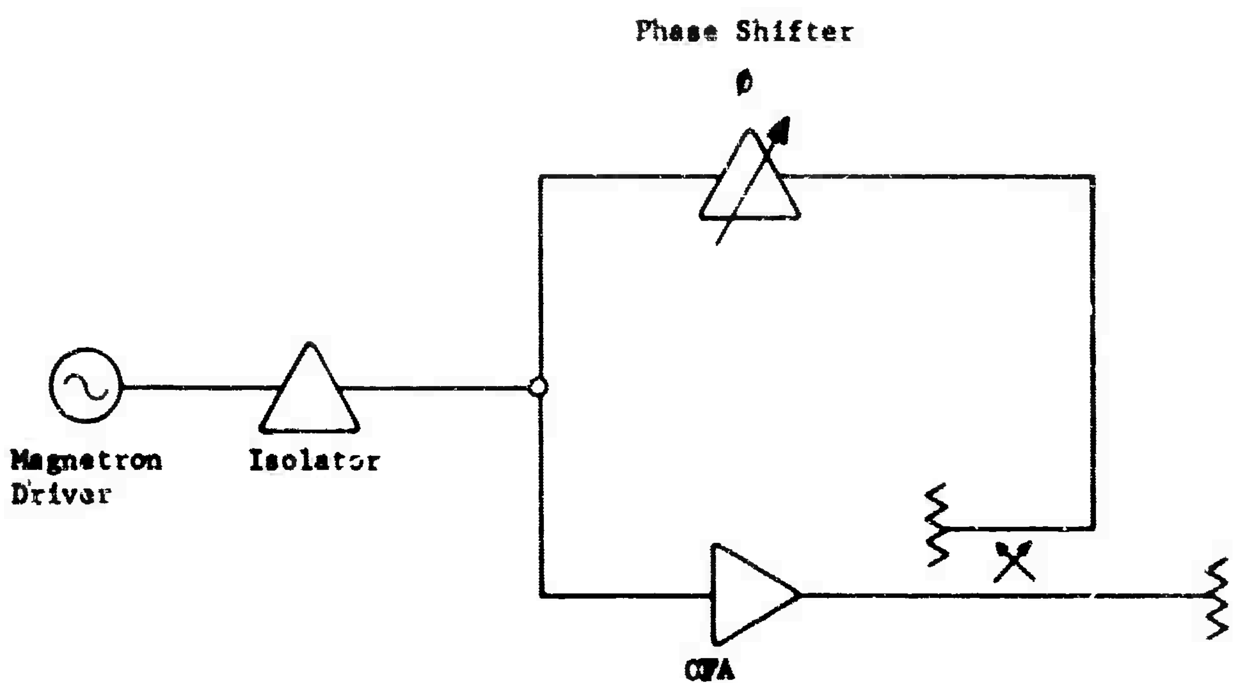
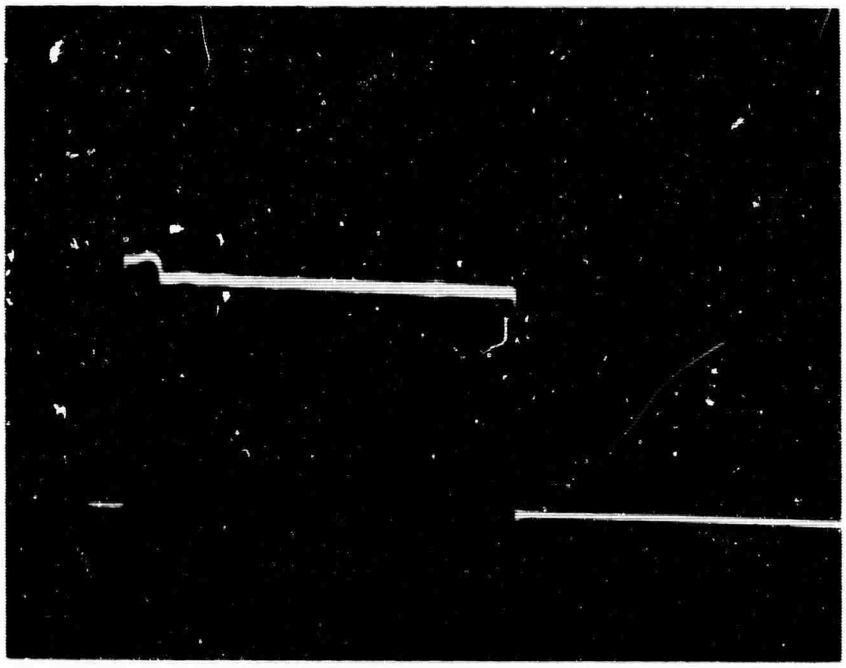


FIGURE 1 FEEDBACK LOOP USED IN LONG PULSE AND HIGH AVERAGE POWER TESTING. THE MAGNETRON TRIGGERS THE CFA ON. WHEN THE MAGNETRON PULSE CEASES THE CFA CONTINUES TO OSCILLATE AT A FREQUENCY DETERMINED BY THE FEEDBACK LOOP UNTIL THE CONTROL PULSE TURNS THE CFA OFF



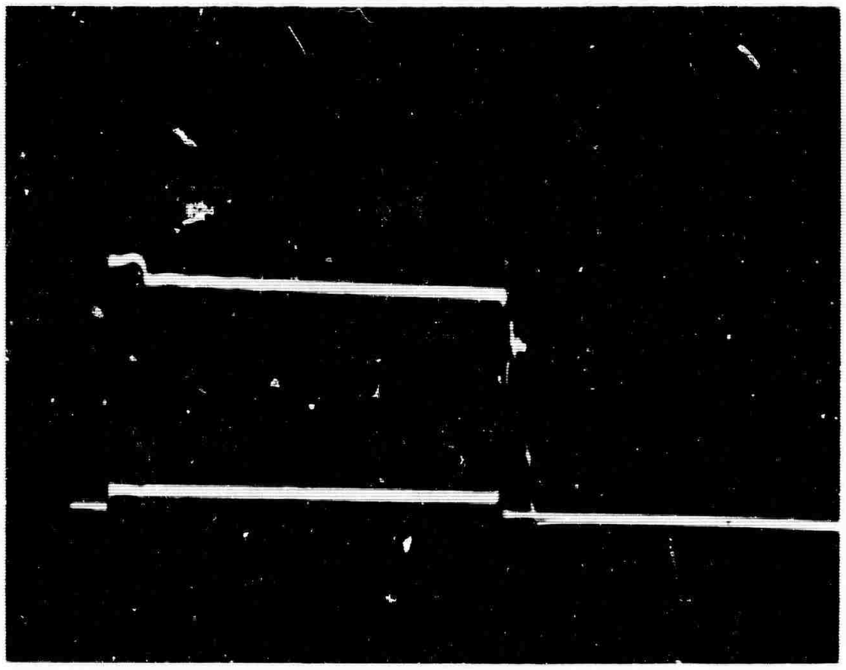


FIGURE 2 AMPLIFIED RF PULSE AND CONTROL PULSE (top) AND RF PULSE ALONE (bottom)

Tube triggered by 2.5 μsec magnetron pulse and allowed to oscillate after cessation of drive pulse under influence of feedback loop until control pulse is applied. Effective RF drive from feedback loop is only ≈ 2 kw peak. This causes sudden drop in RF output when magnetron turns off. Total amplifier pulse length is 25 microseconds.

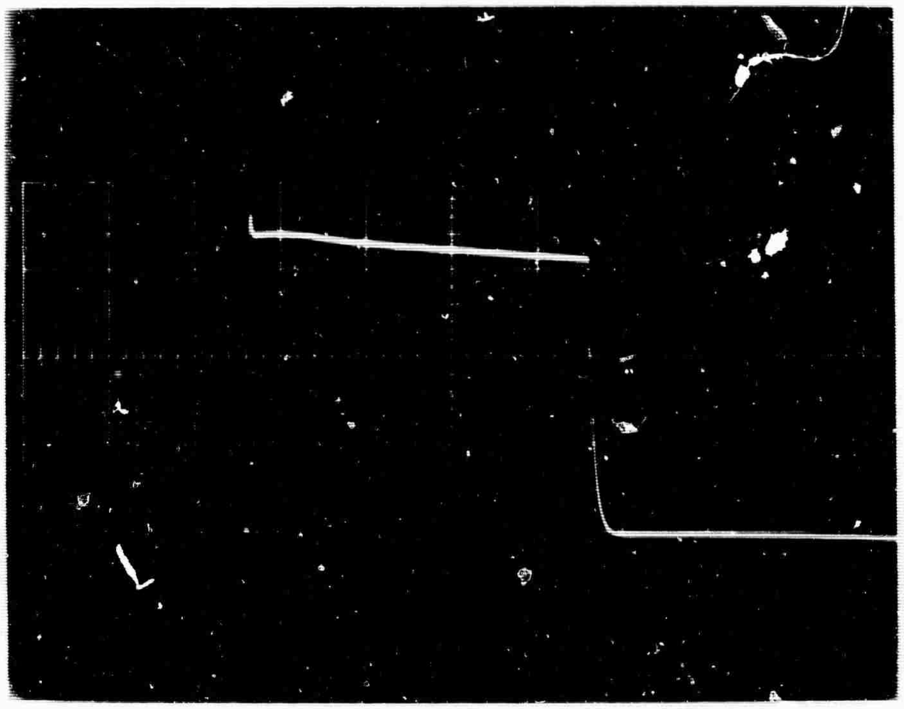


FIGURE 3 RF PULSE SHAPE FOR 200 MICROSECOND PULSE

Crossed-field amplifier operated on feedback loop. Spike on leading edge represents the 2.5 microsecond magnetron drive interval

calculation of the voltage droop on the energy storage capacitor and a knowledge of the dependence of output power on operating voltage as determined from the performance charts.

In these tests, the phase length of the feedback loop was sufficiently long so that self-excitation at several different frequencies within the operating bandwidth of the crossed-field amplifier would have been possible. The adjustable phase shifter was positioned so that one of these regenerative frequencies coincided with the frequency of the magnetron trigger signal. When this was done, the tube continued to operate at the trigger frequency after the termination of the magnetron drive signal. This arrangement hints at the possibility of a sort of "digitalized frequency operation." In such an arrangement, an electrically long feedback loop would be employed so that regeneration would be possible at a number of frequencies within the operating amplifier bandwidth. The frequency at which oscillation actually occurred could then be chosen by the proper frequency of the magnetron trigger signal. At the termination of this trigger signal, the amplifier will continue to oscillate at the regenerative frequency closest to that of the applied trigger signal.

Using this feedback loop technique, average power capability tests were run at a pulse length of 200 μsec up to an average power of 1500 watts. The power limit reached was imposed by the average power capability of the coaxial-line components used in the feedback loop. For example, the directional coupler used as the output power sampler had a rating of 200 watts. On one occasion, heating of this coupler was sufficient to unsolder a connection. The tests at 1500 watts of average power were run for a comparatively short time (less than half an hour) because of the limitations of the coaxial components. However, tests at approximately the 1100 watt average power level were run for several hours on several successive days. On the basis of these tests, we are confident that the present tube design may be

rated for at least 1 kilowatt of average power, and we suspect that a rating of over 2 kw could be justified by further average power testing. During all of these tests, the tube operated cold to the touch and a very moderate air flow over the cathode cooling fins was required to maintain them at a temperature of approximately 60°C.

3.0 LIFE TESTS

Life testing was continued on tubes L30E, L48E and D37F. By the end of December, tubes L48E and D37F were still on test. These tubes had operated for 4932 hours and 2368 hours, respectively. Tube L30E has operated for 1030 hours, at which point, its life test has been interrupted because of equipment difficulties. This life test position is currently awaiting replacement parts for the equipment.

The RF input power to the tubes on life test has been increased to the desired level of 5 kilowatts. As discussed in the last quarterly report, low input power to these tubes had been a source of starting time delay and jitter. With the 5 kilowatt input drive, delay and jitter have been significantly decreased. Tube D37F, which has improved heat conduction from the control electrode, has never had a significant starting delay or jitter problem. This tends to indicate that our interpretation of this problem, in terms of overheating of the control electrode and subsequent surface changes in this element, is correct.

The life test program has now accumulated a total of 11,881 life test hours. A summary of life test results for the Group C tubes is given in Table I.

TABLE I

SUMMARY OF GROUP C SFD-209 TUBE STATUS AND LIFE TEST RESULTS AS OF 8 JANUARY 1965

Tube No.	Serial No.	Seal In Date	Control Electrode Type	Total Life Test Hours	Comments	Present Status
1	H19E	9/13/63	Notched titanium	--	Voltage breakdown through cracked insulator	Rebuilt as H19E-1 with modified insulator
1a	H19E-1	10/8/63	Notched titanium	--	Poor starting performance	Rebuilt as H19E-2
2	J10E	10/19/63	Notched titanium	--	Poor starting performance	Rebuilt as J10E-1
2a	J10E-1	10/28/63	Notched aluminum	750 end of life	Improved starting but still marginal; removed from life test because of excessive starting jitter	Tested to end of life and opened for analysis
3	K6E	11/15/63	Stepped aluminum	223 end of life	Good performance; damaged by equipment failure on life test; some starting jitter appeared on life test prior to failure	Repumped as K6E-1; now awaiting RF test for analysis of jitter problem
4	L1E	12/12/63	Stepped aluminum	1288 end of life	Good performance; damaged by equipment failure on life test; some starting jitter appeared on life test prior to failure	Being analyzed
5	L30E	12/19/63	Stepped aluminum	1030 Cont'g	Performance OK	Awaiting replacement parts for life test equipment
6	L48E	1/2/64	Stepped aluminum	4932 Cont'g	Developed starting delay and jitter of 0.3 μsec	
1b	H19E-2	1/8/64	Stepped aluminum		Performance OK on quick check	Awaiting RF testing
3a	K6E-1	2/6/64	Stepped aluminum		Tube K6E removed from life; repumped as K6E-1 without opening; initial quick check shows starting jitter	Awaiting testing for analysis of jitter problem
7	D34F		Stepped aluminum "Heat shunts" on support assembly		Being repaired and rebui rebuilt	
8	D37F		Stepped aluminum "Heat shunts" on support assembly	2368 Cont'g		On life test and operating

4.0 GROUP D TUBE CONSTRUCTION AND TESTING

Group D tube construction is now complete. RF testing with the exception of phase measurements is also essentially complete. Table II gives a summary of the Group D tube status. At the end of December, the only tube construction effort remaining is the repair of tube D34F of Group C. This repair is now in process.

During the past quarter, four Group D tubes were constructed (H29F, I15F, I28F and J4F). Tube H29F incorporated an absorber behind the capacitive couplers. As discussed in previous reports, this technique produces a selective damping of the pi mode which occurs at the upper band edge. In this manner, we expected to eliminate pi mode interference completely and increase the usable gain of the amplifier. These absorbers were constructed from relatively brittle, machinable ceramic because they could be obtained on a short delivery schedule. Unfortunately they cracked during bake out of the tube and fell against the capacitive couplers, resulting in high circuit loss and severe reflections. The tube was opened and the cracked section of absorber removed. An attempt was then made to repair the tube and pump it again. However, another absorber section cracked during this procedure. This resulted in our finally scrapping tube H29F. Tube L7F, a seventh tube in the Group D series which was originally scheduled for six tubes, was constructed as a replacement for tube H29F.

Tube I15F was constructed similar to the first two tubes of the Group D series but with an anode-cathode spacing intermediate between those of the first two tubes. Initial performance of this tube appeared to be very good. Unfortunately before tests could be run, the input window of the tube was cracked as a result of mechanical strains imposed by a revised coaxial-line set up. The tube was repaired by replacing the input window without opening the main body of the tube. It was then returned to test. Characterization of the

TABLE II SUMMARY OF GROUP D SFD-209 TUBE STATUS AND LIFE TEST RESULTS AS OF 8 JANUARY 1965

Tube No.	Serial No.	Seal In Date	Cathode Diameter	Total Life Test Hours	Comments	Present Status
1	F63F	6/29/64	2.370"			High average power capability evaluated
2	G35F	7/22/64	2.330"		Increased anode-cathode spacing	Evaluated
3	H29F	8/27/64	2.370"		To be reopened	Damaged beyond recovery
4	I15F	9/11/64	2.350"			Evaluated
5	I28F	9/25/64	2.370"			Evaluated
6	J4F	10/6/64	2.370"		Matrix-type cathode	Evaluated
7	L7F	12/8/64	2.370"		End hats modified	Evaluated

tube after this repair showed a significant degradation in its performance level. We suspect this to be a result of degradation of the cathode surface when the tube went down to air. This is the first indication we have had of the degradation of an aluminum cathode surface. This, however, was the result of a highly unusual processing history as outlined above. Characteristics measured on tube I15F are shown in Figures 4 through 6.

Tube I28F was built similar in all respects to tube F63F. The results of measurements on this tube are shown in Figures 7 and 8. The performance was essentially similar to that of tube F63F.

Tube J4F was similar to tubes F63F and I28F in all respects, except that a matrix type impregnated cathode was employed in place of the usual aluminum cathode. This cathode was obtained from Semicon Associates. It was impregnated with a mixture usually employed in S-F-D laboratories' magnetrons and higher frequency crossed-field amplifiers. The cathode was outgassed to a temperature in excess of 800°C in a bell jar before incorporating it into the tube. However, because the tube has no heater, there was no means of activating the cathode once inside the tube. It was the belief of Semicon Associates that this was not necessary for a cathode to be employed as a secondary emitter; i.e., that activation was necessary only to develop thermionic emission but not secondary emission. There is good reason to believe that this would be the case, since the impregnant includes a large amount of aluminum oxide which is known to be a good secondary emitter, even before cathode activation. This procedure has been used successfully at S-F-D laboratories on X-band crossed-field amplifiers employing liquid cooled cathodes. Experiments using a secondary emission tester had also demonstrated a secondary emission ratio at least equal to that of aluminum. Tests on tube J4F, however, showed very poor performance. It would appear that these results could only be attributed to a comparatively inactive cathode surface. Some of

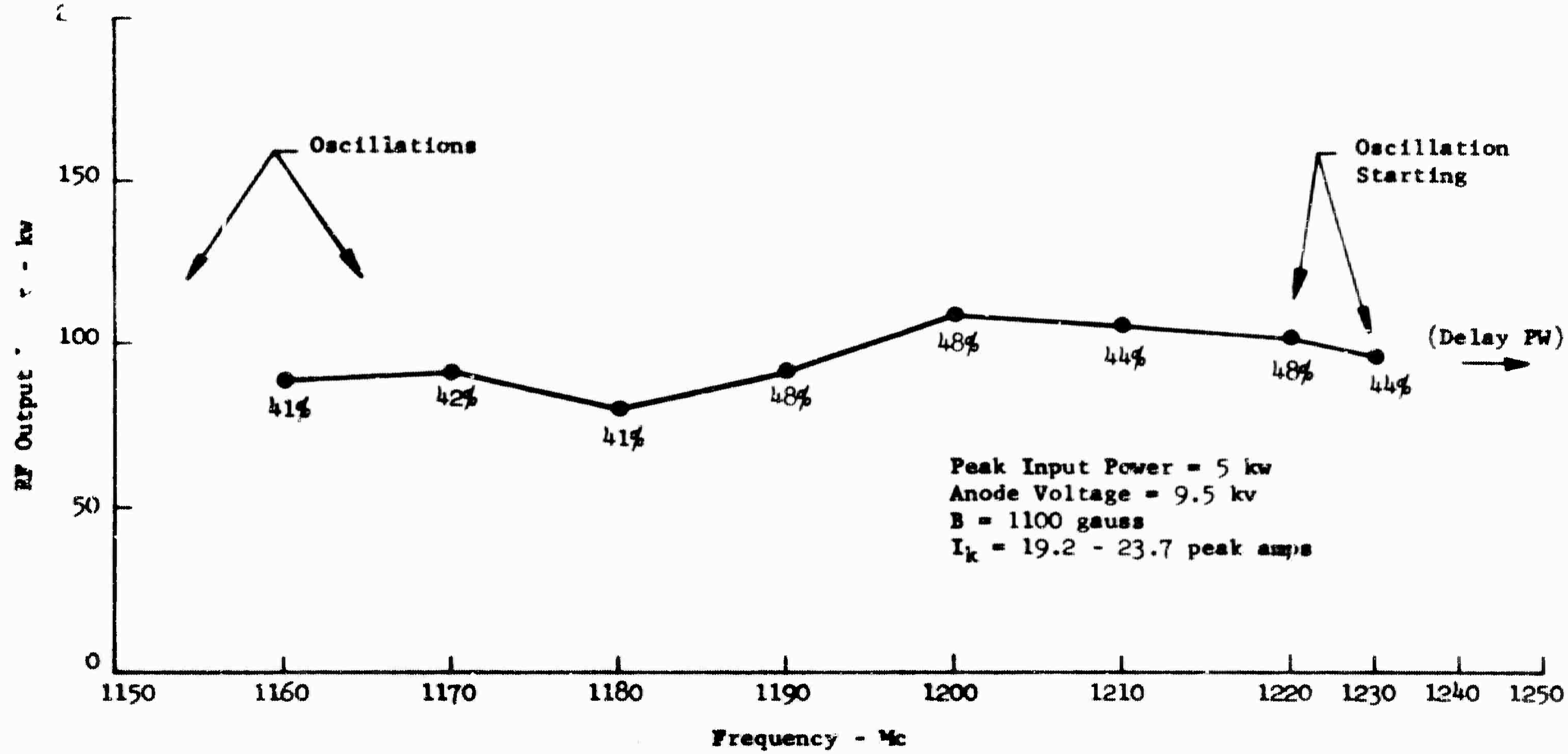


FIGURE 4 OUTPUT POWER VERSUS FREQUENCY AT FIXED ANODE VOLTAGE FOR SFD-209, TUBE I15F

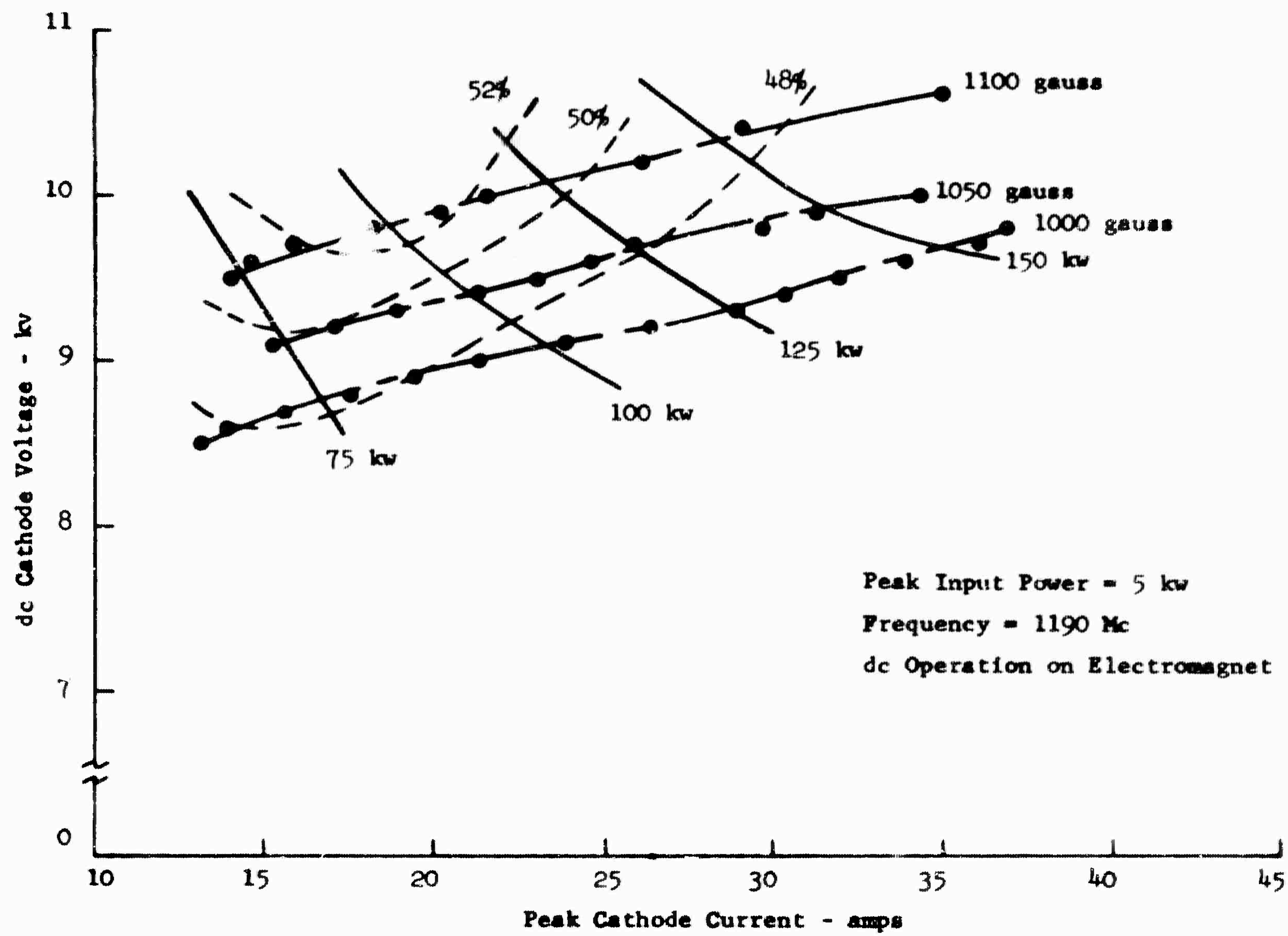


FIGURE 5 PERFORMANCE CHART FOR SFD-209, TUBE I15F

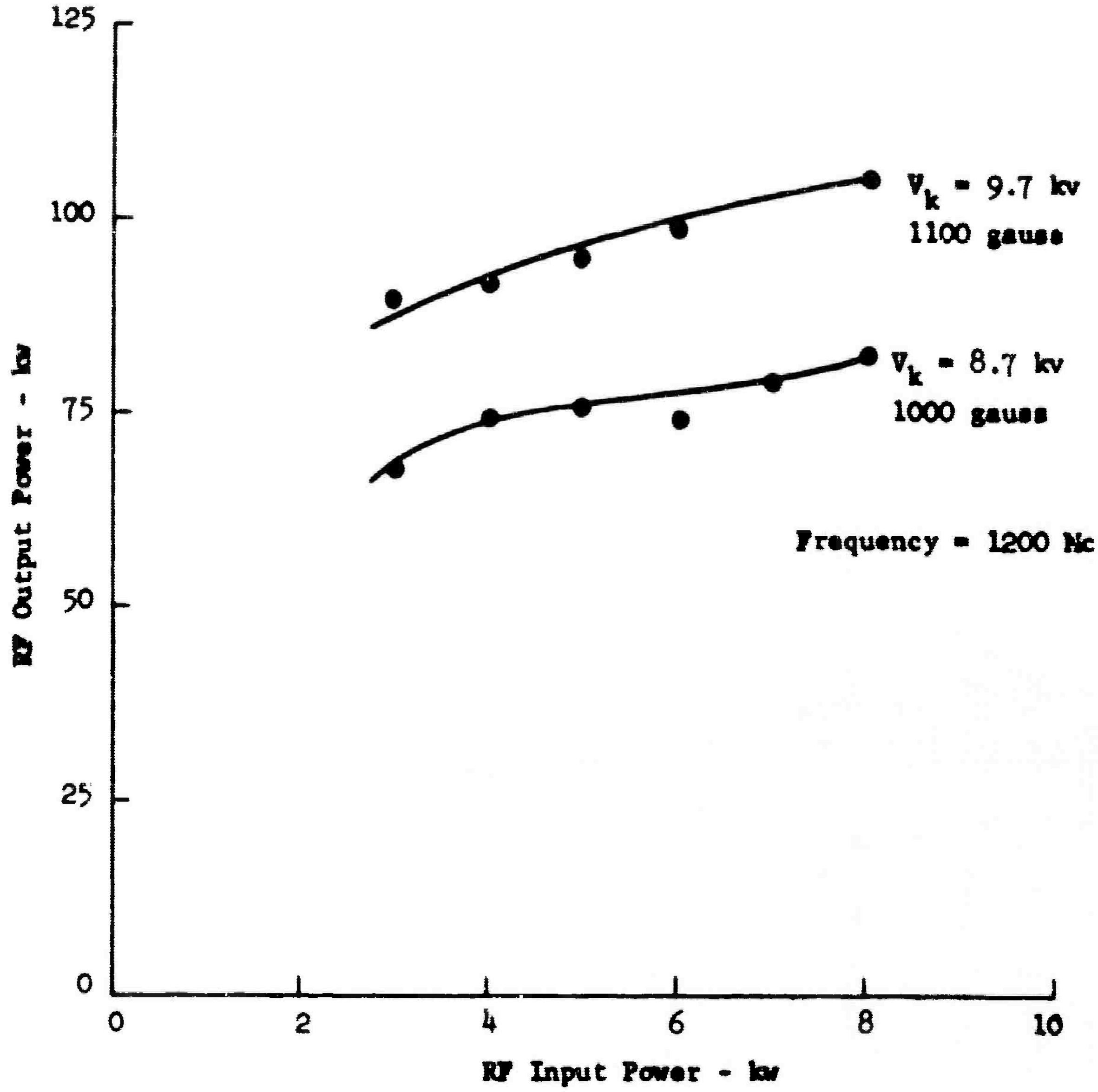


FIGURE 6 POWER OUTPUT VERSUS POWER INPUT AT FIXED VOLTAGE FOR SFD-209, TUBE I15F

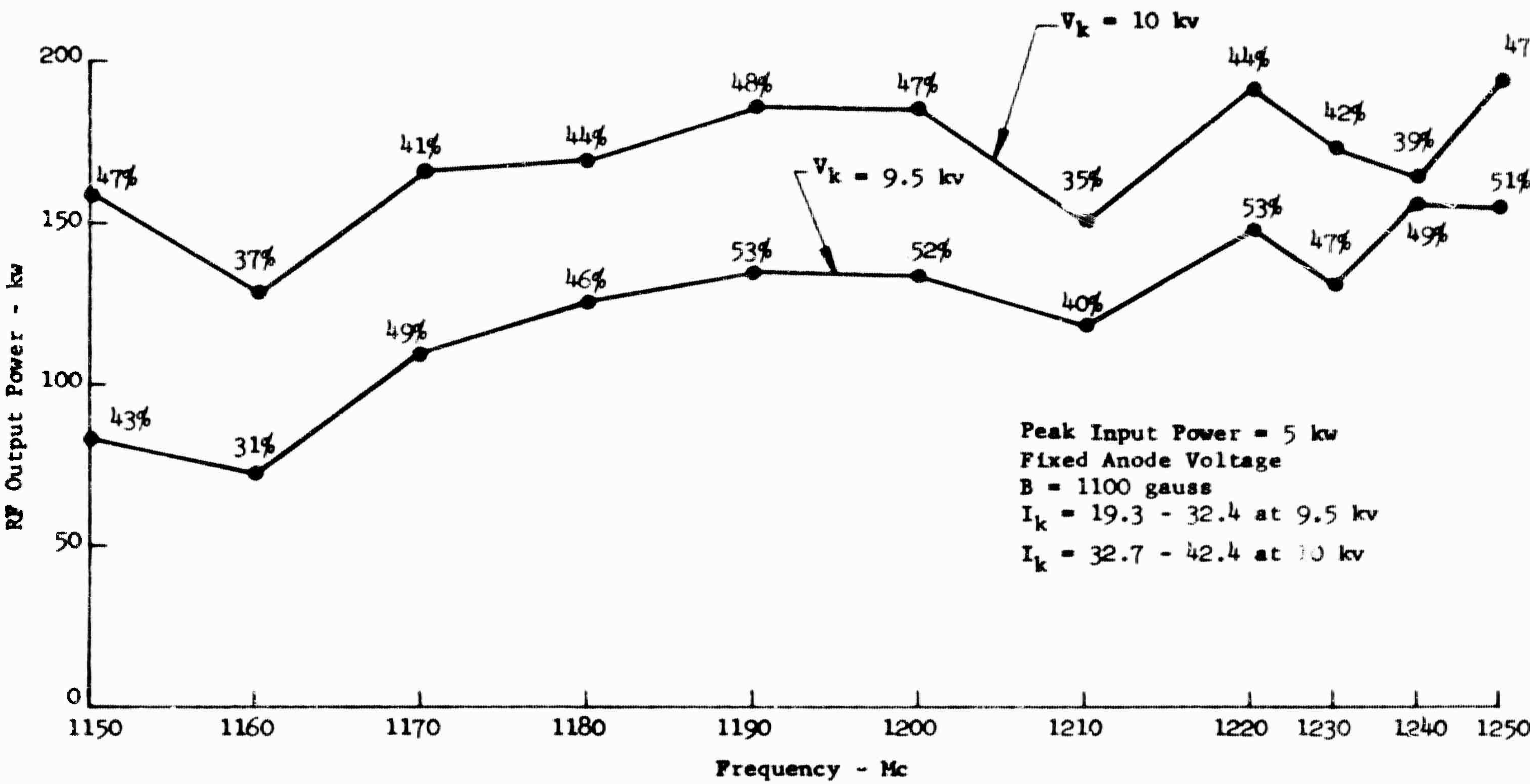


FIGURE 7 OUTPUT POWER VERSUS FREQUENCY AT FIXED ANODE VOLTAGE FOR SFD-209, TUBE L28F

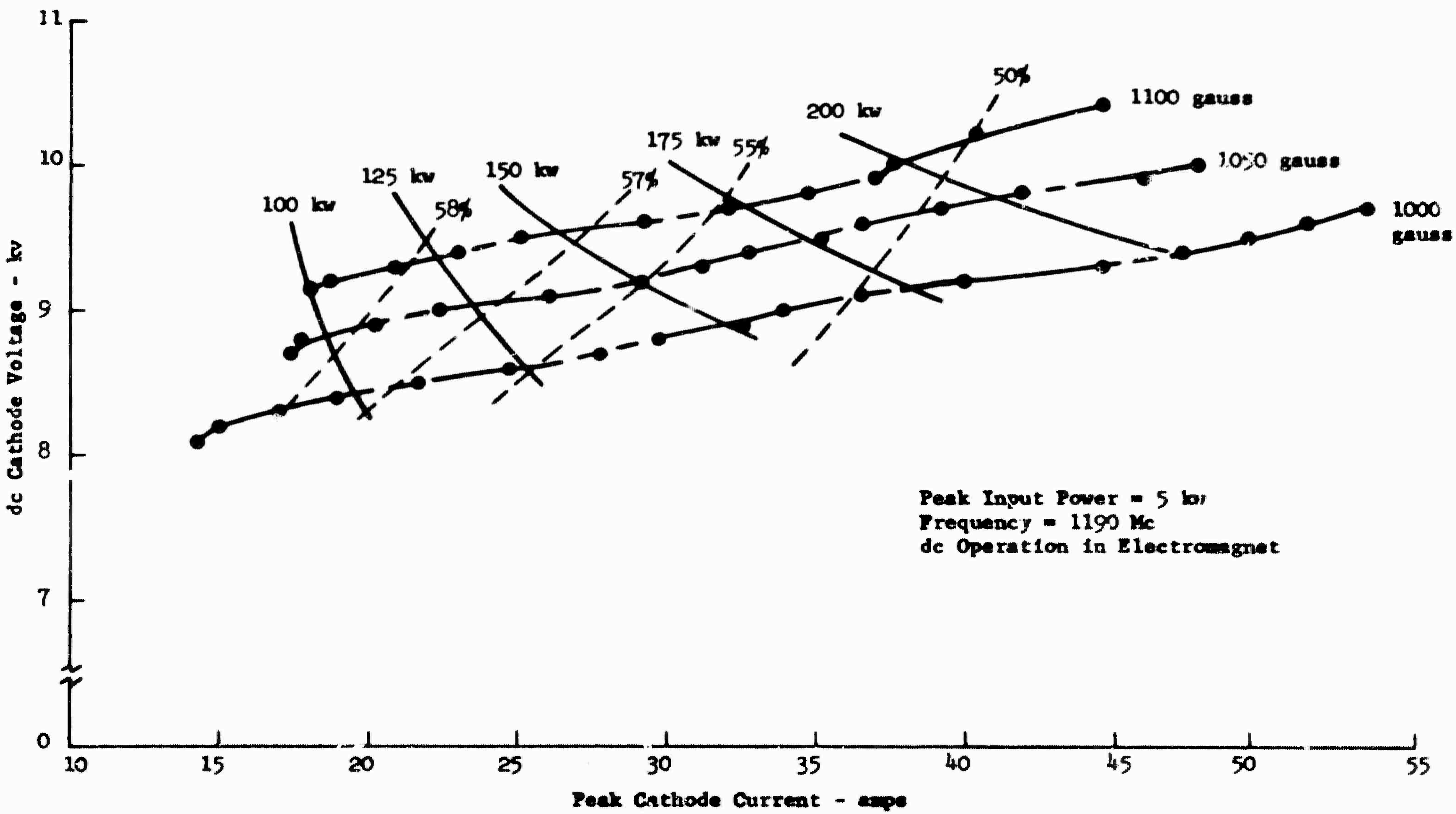


FIGURE 8 PERFORMANCE CHART FOR SFD-209, TUBE 128F

these results are shown in Figure 9. We can only conclude that somehow we have not managed to obtain as high a secondary emission ratio in these experiments as we have at X-band. This could be connected with the difficulties we encountered in heating the large L-band cathode in a bell jar. The temperature of 800°C obtained in this step is significantly lower than the temperature to which the X-band cathodes are exposed.

Tube L7F was constructed similar to tubes F63F and I28F in all respects, except that the end hat diameter was made larger so that the end hats extended half the distance from cathode to anode rather than the usual one-third of the distance. This change was made because results of an X-band crossed-field amplifier program indicated an improvement in efficiency by as much as 5 percentage points when the end hat extension was increased from one-third to one-half of the anode-cathode spacing. Results measured on tube L7F are shown in Figures 10 through 12. The performance chart of Figure 10 shows a significant increase in efficiency as a result of the large diameter end hat. Note that the shape of the efficiency contours on this performance chart is different from that for the smaller diameter end hat design as shown in Figures 5 and 8. The increased end hat diameter has resulted in flatter efficiency contours resulting in maintenance of high efficiency to higher values of operating current than has previously been the case. These flatter efficiency contours represent a very marked change as compared with the shape of efficiency contours seen in a number of previous tubes. Therefore, we are justified in drawing a direct cause-and-effect relationship between the higher efficiency and the changed end hat diameter. The design criteria perviously employed called for the end hats to extend one-third of the cathode-anode spacing. This was based on previous magnetron experience. The results on our X-band and L-band crossed-field amplifier programs now indicate that these magnetron criteria

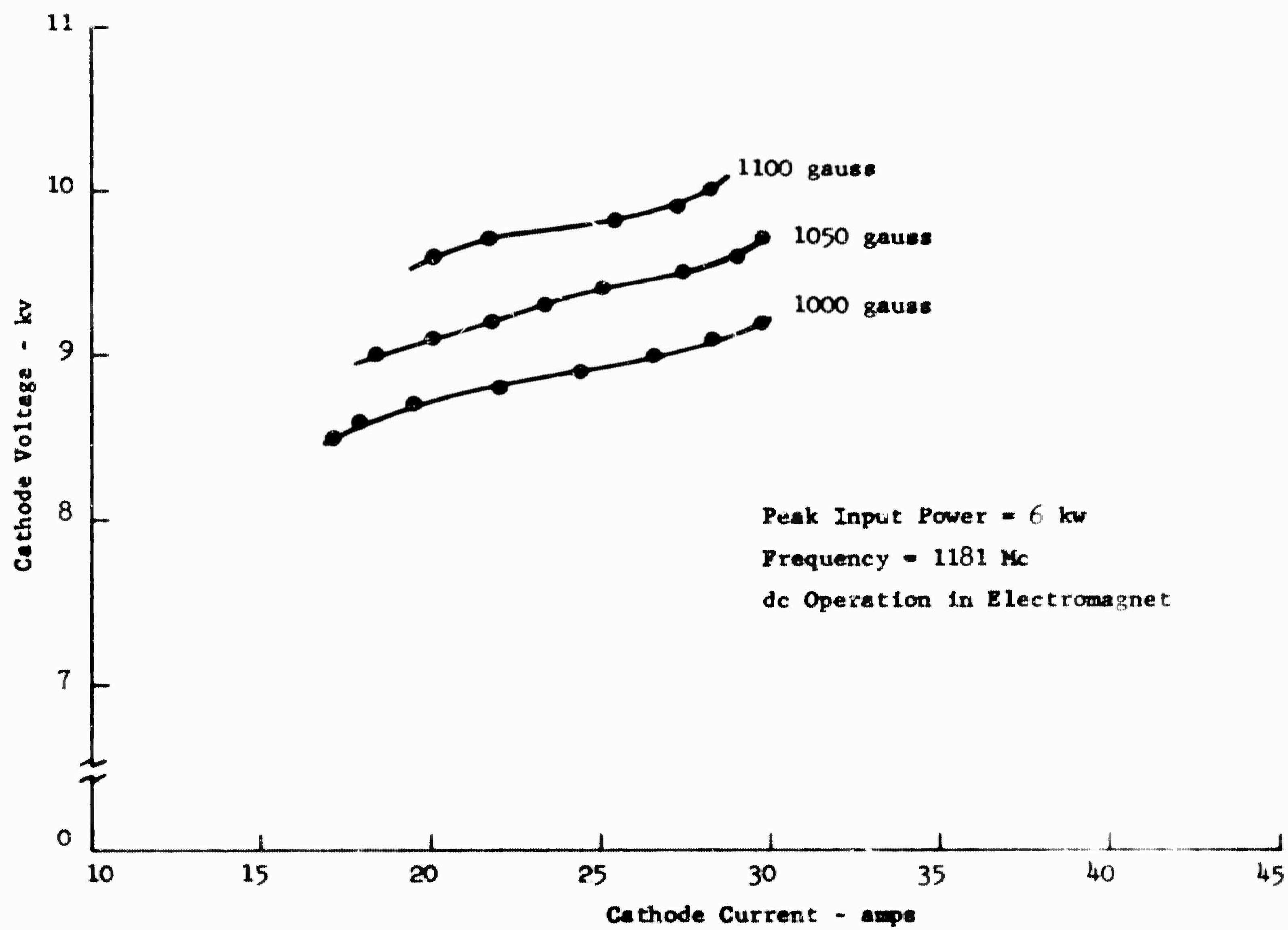


FIGURE 9 PERFORMANCE CHART FOR SFD-209, TUBE J4P

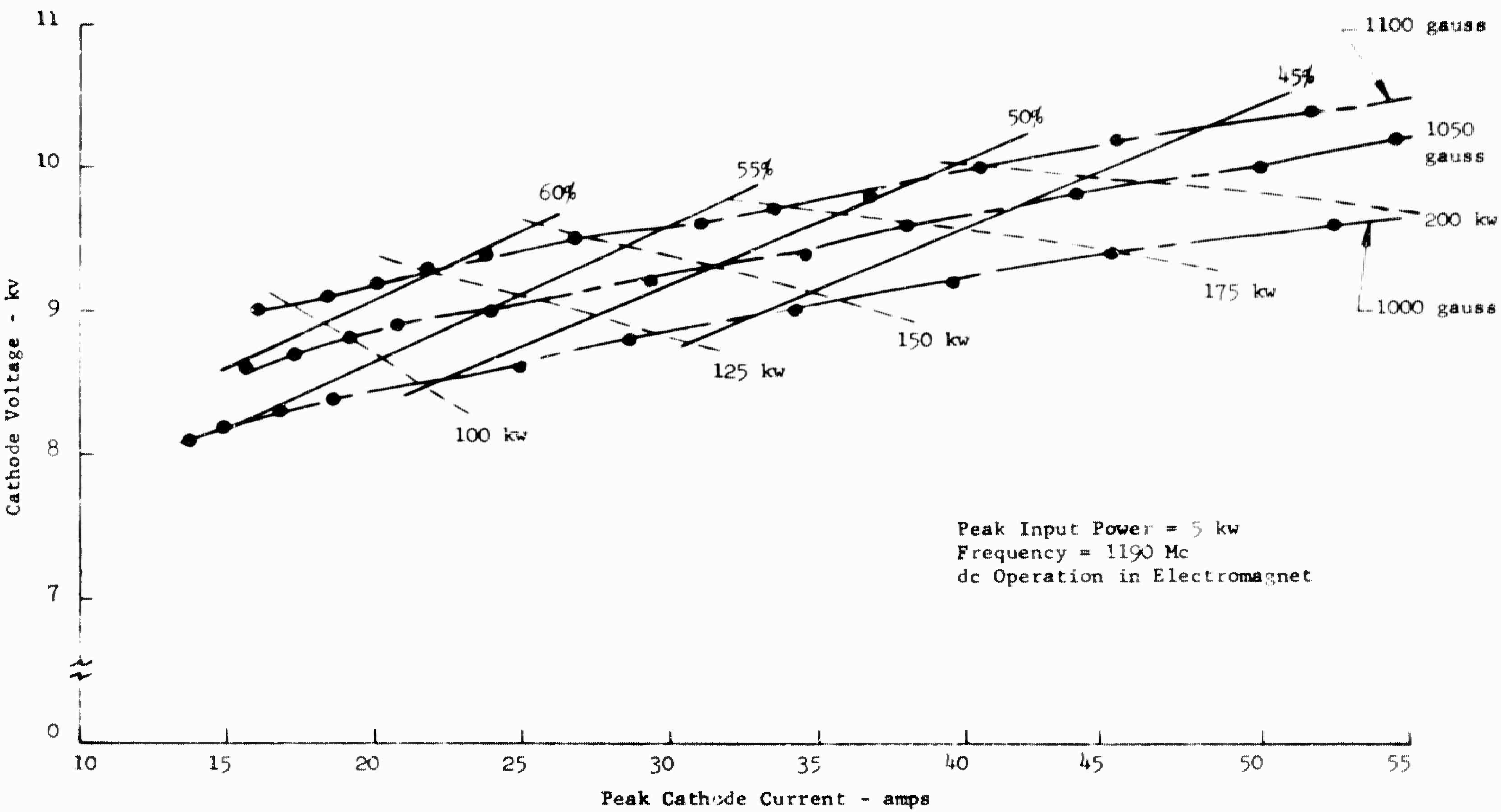


FIGURE 10 PERFORMANCE CHART FOR SFD-209, TUBE L7F

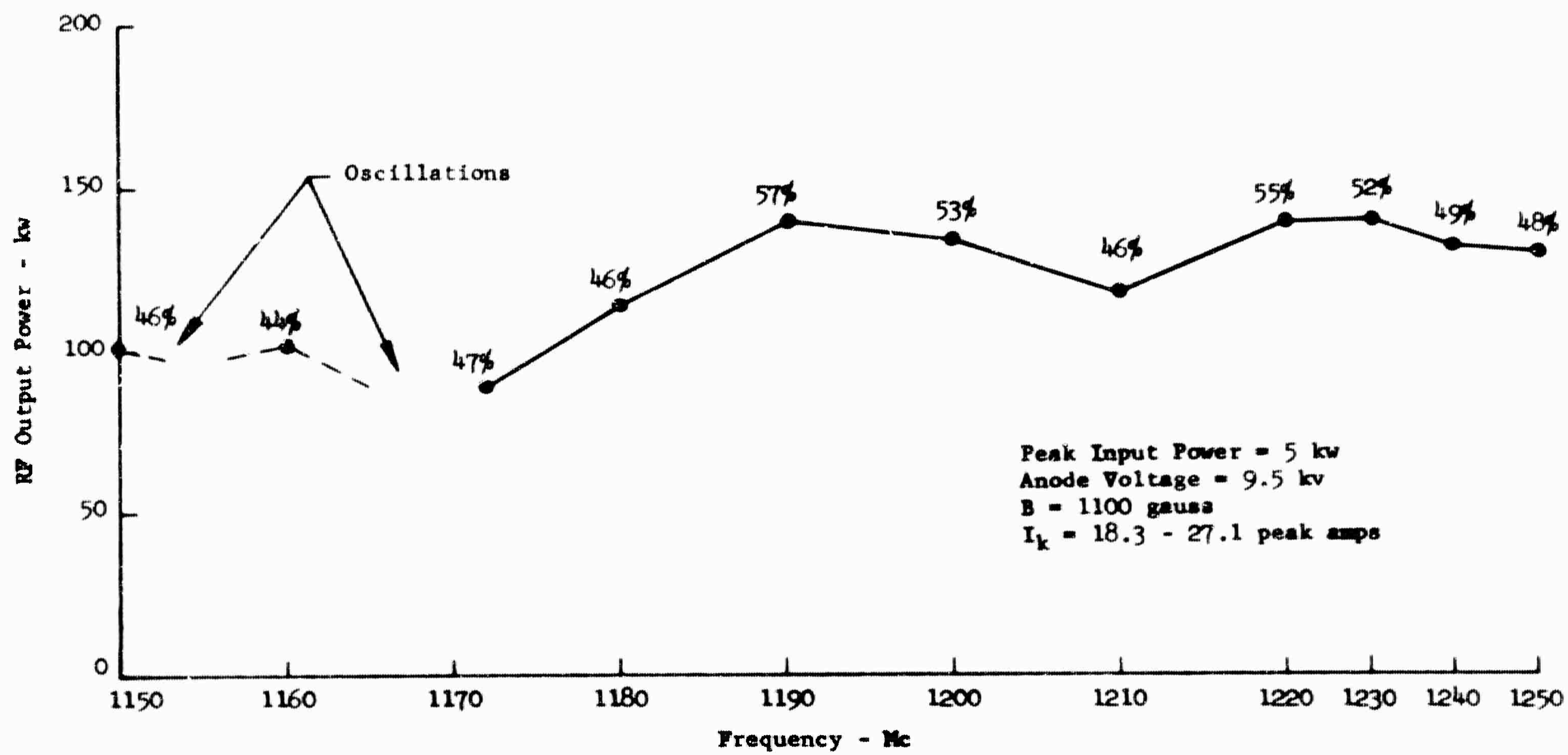


FIGURE 11 OUTPUT POWER VERSUS FREQUENCY AT FIXED ANODE VOLTAGE FOR SFD-209, TUBE L7F

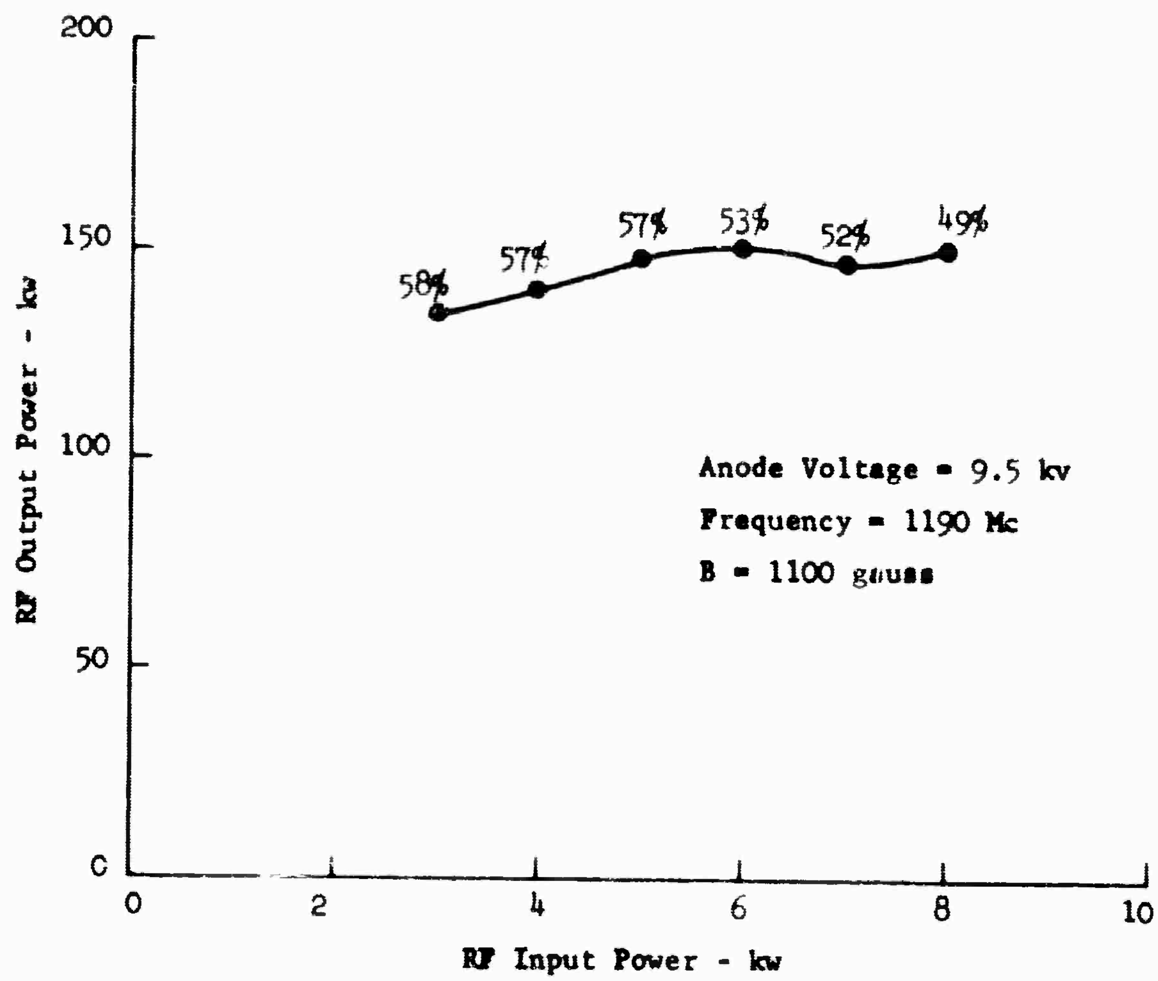


FIGURE 12 POWER OUTPUT VERSUS POWER INPUT AT FIXED VOLTAGE FOR SFD-209, TUBE L7F

are not adequate for crossed-field amplifiers and that additional space charge confinement is required. This is probably the result of electrons in the amplifier requiring a comparatively longer time to travel from the cathode to the anode because of the lower RF field strengths. This would be especially true near the input of the tube. During this longer transit interval, the axial space charge forces can be more effective in forcing the electrons axially out of the interaction region. It is therefore not unreasonable that a higher degree of axial confinement is required in a crossed-field amplifier than in a magnetron.

The frequency response curve for tube L7F shows two holes near the lower frequency end of the band. These resulted from a poor match in these regions. As a result of the poor match, the tube did not amplify properly at these frequencies and instead oscillated at a band edge frequency. In general, the match of Group D tubes has not been as good as that of the good Group C tubes. Figures 13 and 14 compare the transmission and impedance matching characteristics of tube D37F of Group C and tube L7F of Group D. The latter tube has the poorest match encountered among the Group D tubes. In both Figures 13 and 14, the match represents the reflection from a completed tube with a termination on the opposite port of the tube, and thus represents the results of reflections from both the tube input and the tube output. A single one of these transducers would have a reflection equal to about half of that of the maximum values shown by the interference pattern. Figures 13 and 14 show a much better match in tube D37F of Group C than in tube L7F of Group D. This better match is reflected in the tube performance. The characteristics measured on tube D37F, as shown in Figures 3 and 4 of Report No. 7 on this program, are the best we have yet obtained. Throughout the construction of the Group D tubes, we have been looking for the significant difference that has resulted in the poorer matches of the Group

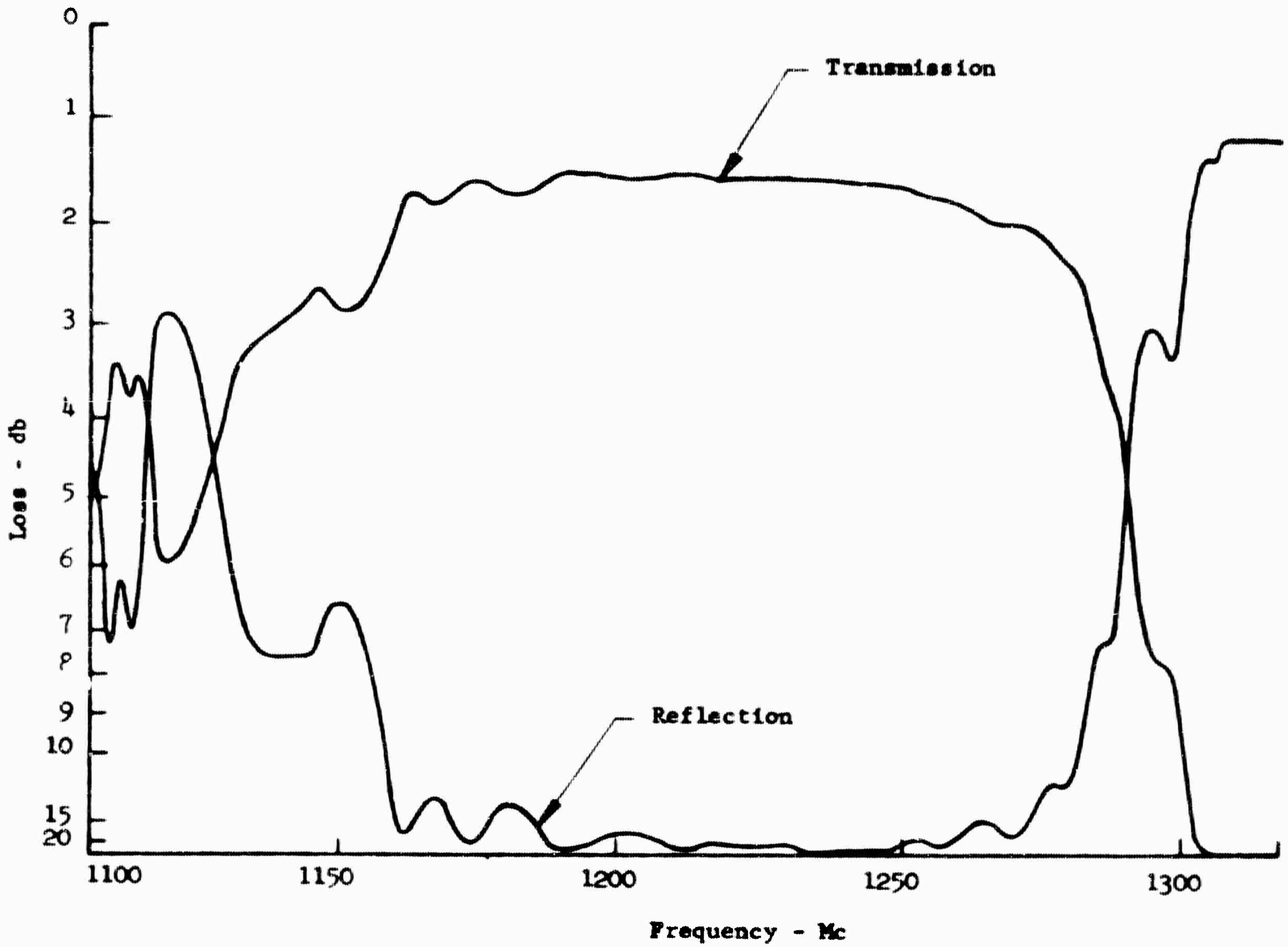


FIGURE 13 TRANSMISSION LOSS AND RETURN LOSS AS A FUNCTION OF FREQUENCY FOR SFD-209, TUBE D37F

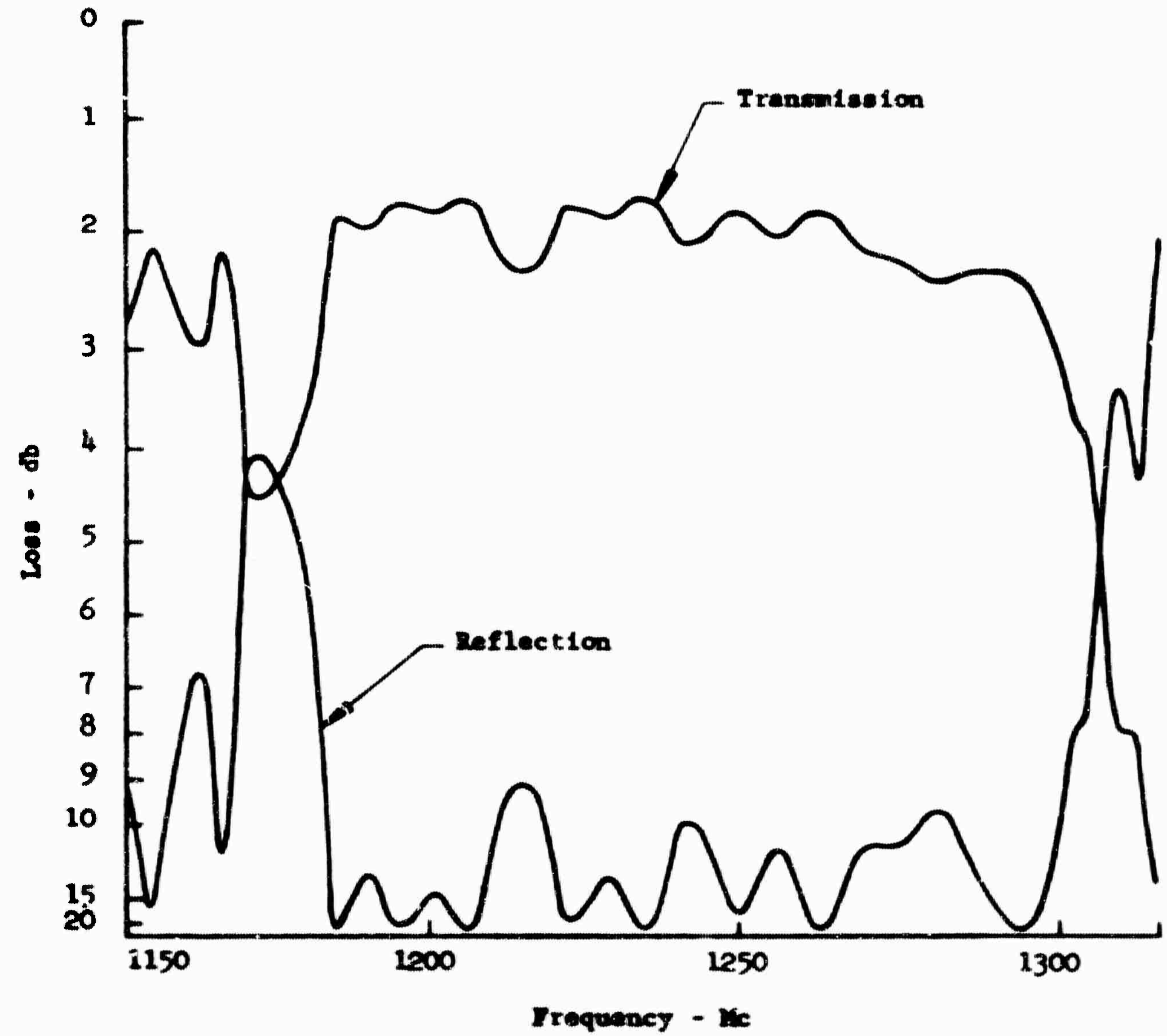


FIGURE 14 TRANSMISSION LOSS AND RETURN LOSS AS A FUNCTION OF FREQUENCY FOR SFD-209, TUBE L7F

D tubes. On some Group D tubes, we have never been able to get a match as good as that on tube D37F. On others, we originally obtained a good match, but the match degraded on successive steps during assembly and bake out of the tube. We originally suspected problems with the output coaxial line and U-bend, and we still believe that some of the problems may be associated with this assembly. However, during the past quarter, two additional sources of variations of the impedance match have been discovered. Both of these are quite subtle. One has to do with the exact shape of the matching tab which is used to apply a capacitive susceptance in shunt across the first resonator. Depending on exactly how this tab is shaped, there is a different ratio of the capacity introduced from the coaxial line to the first and to the second anode circuit bar. A comparison of the tab shape in tube H29F of Group D, which has been opened, with the tab shapes of Group C tubes, which have been opened, shows that there has been a significant change in this shape between the two groups of tubes. This tab is hand formed during the assembly process and the change in shape apparently coincides with a change in the assembler assigned to the program. In the future, this problem may be avoided through a change in the matching tab design. The tab may thus be split into two sections - one section will introduce capacity only from the coaxial line to the anode circuit bar and will be so shaped that negligible capacity is introduced to the second bar; the second portion of the tab will be used to adjust capacity from the coaxial line to the second anode bar. This tab will overlap the capacitive coupler extending from the coax to the second bar, since this adjustment is in parallel with this coupler. In this manner, the exact shape of the tabs used for this matching procedure will become uncritical and essentially the lumped capacity introduced from coaxial line to the first and second anode bars will be the only parameter of significance.

Another source of variation in the impedance match is believed to be the motion of the first anode bar during the braze of the windows and coaxial line assemblies or during bake out. This first bar is connected by a rigid connection to the center conductor of the coaxial line. Because of difficulties in induction brazing of the output coaxial line assembly, we suspect that significant stresses are applied to this center conductor. This may cause the center conductor to move slightly. If this center conductor is off center by a moderate amount, there is still very little reflection introduced. However, the motion of this conductor can also push the first bar of the circuit, causing it to move underneath the matching tab. Since the spacing between the first anode bar and the matching tab is critical, this produces a significant change in the circuit match. A more flexible connection between the first anode bar and the center conductor of the coaxial line thus appears to be in order. Along with this, a rearrangement of the coaxial line assembly procedure so as to eliminate stresses during the brazing operations is required.

The results of measurements on tubes F63F and G35F of Group D have been compared to see the effect of the 10% increase in the anode-cathode spacing. An important scaling variable for crossed-field devices is known as the characteristic current. This current is given by

$$I_c = 8.96 \times 10^{-6} V_o^{3/2} \frac{h}{d} \frac{r_a}{d} R_1 \frac{\theta}{2\pi}$$

where $R_1 = 3r_a^2 r_c/(r_a + r_c)^3$

h is the cathode axial height

V_o is the synchronous voltage

r_a is the anode radius

r_c is the cathode radius

$\theta/2\pi$ is the fraction of a full circle encompassed by the active circuit

d is the anode to cathode spacing

It is seen that the characteristic current is inversely proportional to the square of the anode-cathode spacing. Characteristic currents calculated at band center for tubes F63F and C35F are 24.7 amperes and 19.7 amperes respectively. The peak output power from a crossed-field device is given by

$$P_o = \eta \frac{V}{V_o} V_o I_c$$

where P_o is the power output

η is the efficiency factor (% efficiency/100)

V is the operating voltage

and the other symbols are as defined above.

The output power is thus a function of the characteristic current. For an output of 150 kw peak, a tube having the normal anode-cathode spacing of tube F63F operates at about 1.5 times characteristic current. This is comparatively high for crossed-field devices with operation at about 1 times characteristic current being more typical. The performance charts for the tubes, however, show that efficiency tends to maximize near the 1 times characteristic current. This is also quite typical for magnetrons. To see if the scaling law for a characteristic current can be properly applied to the SFD-209 type of tube, we have plotted the performance charts for tubes F63F and G35F in terms of normalized parameters. (A number of charts of this sort are presented for magnetrons in Collins*.) On this chart, the abscissa is normalized by the characteristic current

*George B. Collins, MICROWAVE MAGNETRONS, McGraw-Hill Book Company, Inc., Vol. 6, MIT Radiation Laboratory Series (1948), Chapter 10

The ordinate is normalized by the synchronous voltage which is given by

$$V_o = \frac{v_o^2}{2 \frac{e}{m}}$$

where v_o is the wave phase velocity
e/m is the charge to mass ratio for an electron

and the magnetic field is normalized by

$$B_o = \frac{v_o}{\frac{e}{m} d} R_2$$

where $R_2 = 2r_a/(2r_a - d)$

and the other symbols are as defined above

As the anode-cathode spacing is increased, the magnetic field must be decreased for the same V/V_o ratio. This results from the lowered dc electric field at the increased spacing. To maintain the same E/B electron drift velocity, the magnetic field must be correspondingly reduced. Figure 15 shows that the curves for F63F and G35F practically coincide when plotted in normalized coordinates. Further, they show that increasing the anode-cathode spacing does not cause any significant degradation in efficiency. Thus the scaling law for anode-cathode spacing applies to this case. As was reported in the last quarterly report, the increased spacing results in a significant decrease in the range of currents over which band edge oscillations occur. Figure 16 shows the location of the mode boundary for the spacings of tubes F63F and G35F. Stable operation occurs to the right of these mode boundaries and band edge oscillations occur to the left of them. The increased anode-cathode spacing has resulted in the mode boundary for tube G35F being moved to approximately

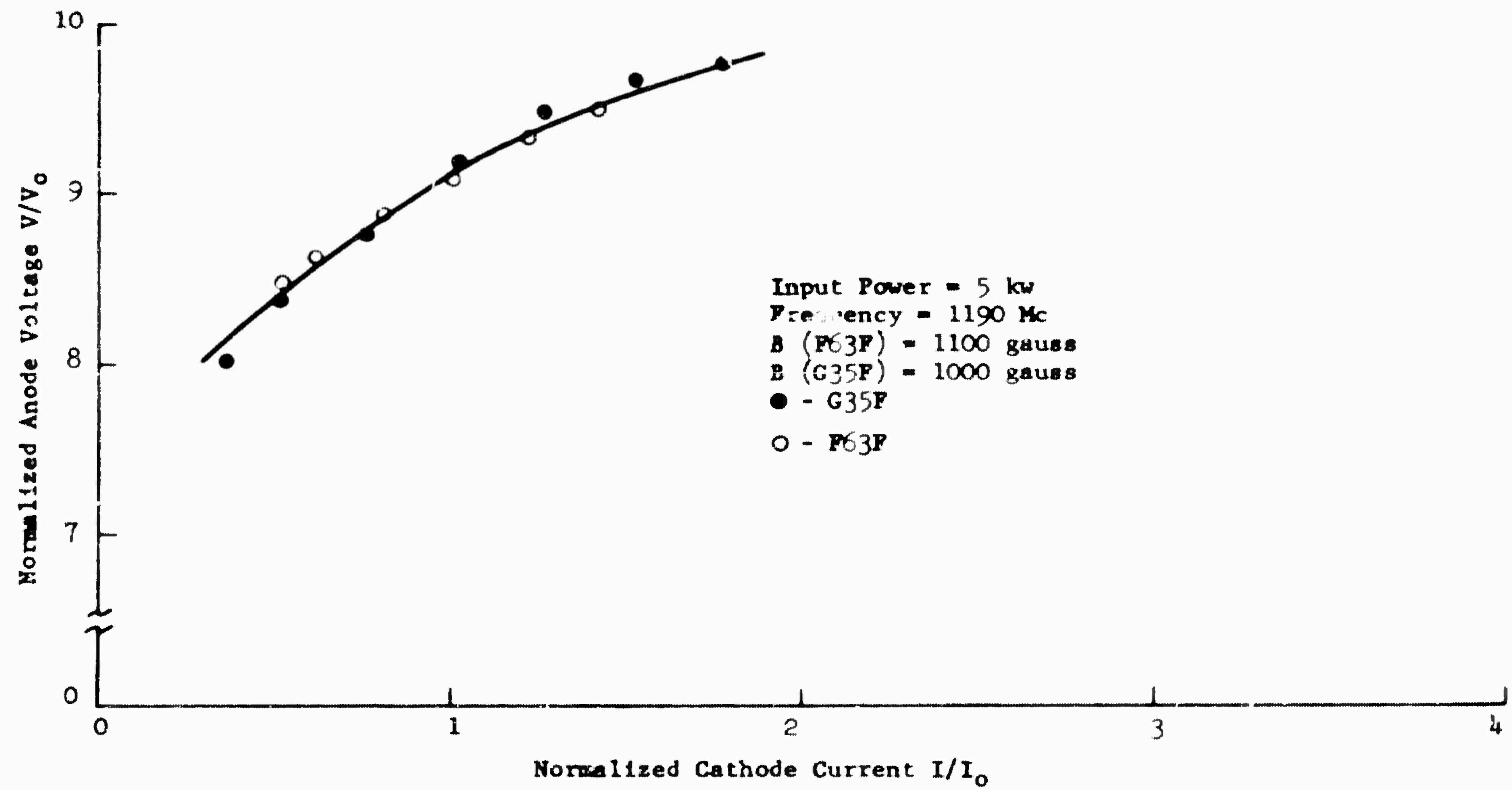


FIGURE 15 NORMALIZED PERFORMANCE FOR SFD-209, TUBES F63F and G35F

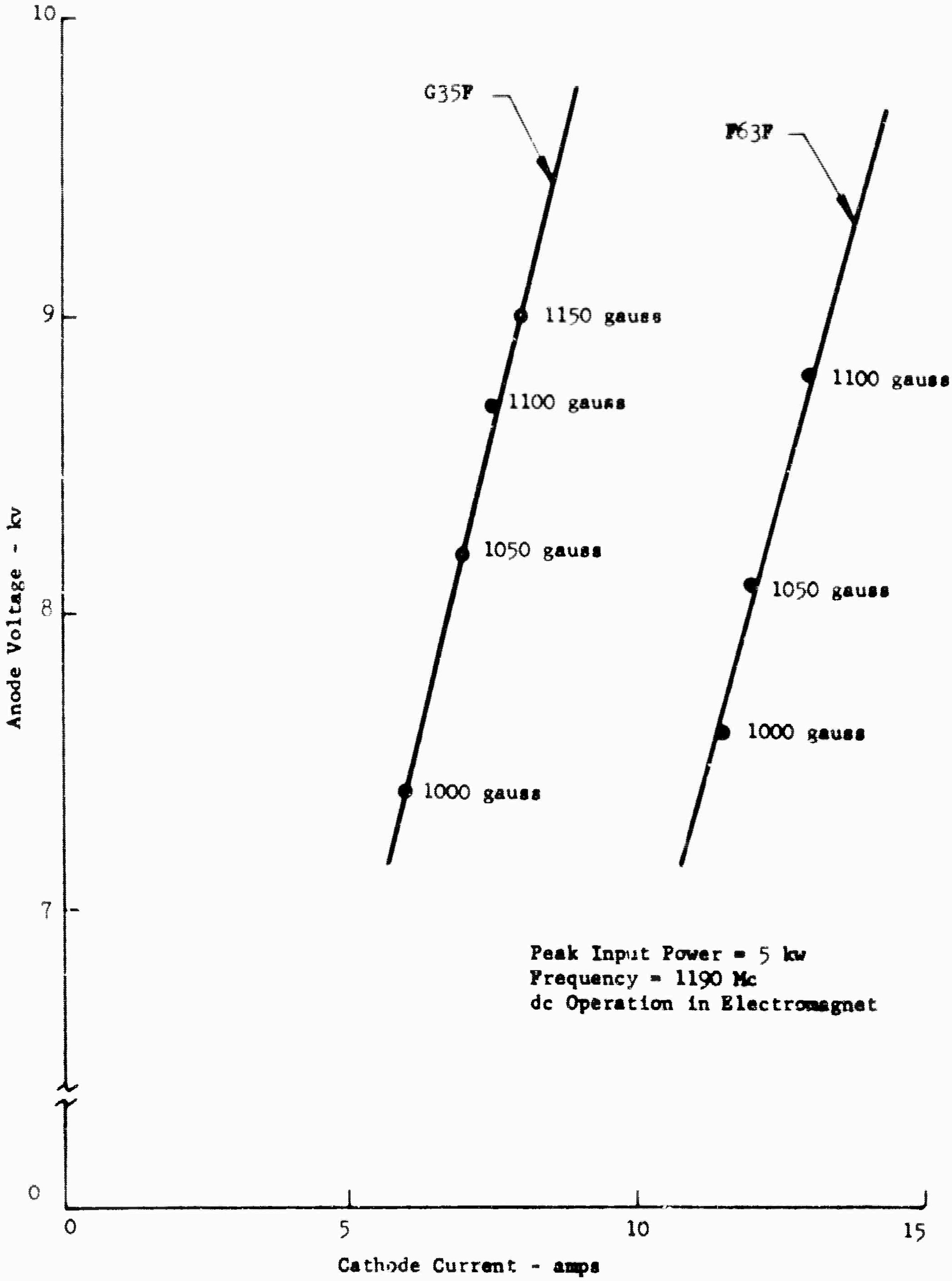


FIGURE 16 MODE BOUNDARY LOCATION FOR SFD-209, TUBES G35F and F63F

one-third of the current of tube F63F. Thus, it is seen that at some sacrifice in output power (approximately 1 db), the tendency to pi mode oscillation at low currents may be decreased. In some applications, this may be necessary where operation over a wide range of powers is required.

5.0 CONCLUSIONS

The conclusions which may be drawn from the effort during this quarter are:

1. The variations in impedance match from tube to tube can be traced to problems associated with the design of the susceptive matching tabs and the output and input line assembly techniques. These difficulties may be alleviated by straightforward redesign in these portions of the tube. When this is done, we anticipate no difficulties in reproducing the impedance matching characteristics of tube D37F which are shown in Figure 13. Performance of the tubes has been sufficiently alike so that we can confidently predict that the desirable characteristics of tube D37F will then be obtained on all of the units produced.

2. Efficiency can be increased even as compared with the results obtained on tube D37F by an increase in the end hat diameter. This should raise the efficiency to above 50% at all frequencies in the operating band.

3. The dependence of performance characteristics on the anode-cathode spacing is as predicted by the scaling laws.

4. Matrix impregnated cathodes, processed in accordance with standard techniques, do not necessarily develop a high secondary emission ratio. Further study of the processing of such cathodes is required if they are to be used. At present the advantages appear to lie with the aluminum cathodes.

5. The Group D design of the SFD-209 tube has an average power capability of at least 1 kw at a 200 μsec pulse length. It is probable that the average power capability of the present design is in excess of 2 kw.

6.0 PROGRAM FOR NEXT INTERVAL

1. Conduct phase measurements.

2. Continue life tests.

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